How Do Magmatic Systems Evolve and Under What Conditions Do Volcanoes Erupt?

Expected Accomplishments

- *Up-to-date global inventory of active terrestrial volcanoes*
- *Further definition of the relationships among deformation, seismicity, intrusions, and eruptions*
- *Volcanic activity warning system*
- *Forecasting of volcanic activity on progressively longer time scales*

Benefits for the Nation

- *Detection of ash and plume products to provide warnings for air travel*
- *Hazard mitigation due to improved volcanic activity warnings*
- *Advanced planning for high-risk populations near volcanic regions*

The Challenge

Volcanoes are direct links to the interior of the Earth, and their eruptive power and often-long intervals of quiet dormancy inspire fear and, in some societies, reverence. We are entering a period of rapid growth in our understanding of volcanoes, as diverse measurements are integrated and new observational tools are developed. Because eruptions are episodic and occur throughout the globe, we must rely on methods that give us observations of volcanic activity everywhere on the planet. Primary to our understanding of eruptive systems are the identification and characterization of active volcanoes. From the volcanoes rimming the Pacific to new eruptions on the ocean floor, there are thousands of volcanoes whose level of activity is poorly known. Indicators of activity include surface deformation, seismicity, thermal emissions, changes in gravity, emission of gasses, and actual eruptions. We know little, however, about how these phenomena are interrelated. The physical mechanisms that cause surface deformation and those that control the rates and styles of eruptions are poorly understood. The ability to predict the timing, magnitude, and style of volcanic eruptions is an important but generally unmet goal.

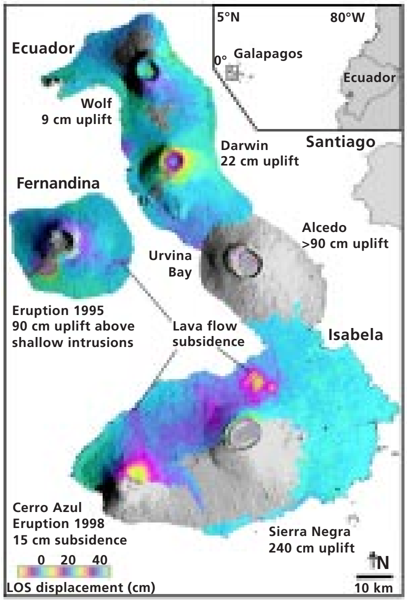
"A cloud... shot up to a great height in the form of a very tall trunk, which spread itself out at the top into a sort of branches. This phenomenon seemed ... extraordinary, and worth further looking into."

Pliny the Elder on the eruption of Mount Vesuvius, 79 AD

The 1980 eruption of Mount St. Helens, triggered by a magnitude 5.1 earthquake, dramatically affected the northwest U.S. Four hundred meters of the peak collapsed or blew outwards. As a result, 650 square kilometers of recreation, timber, and private lands were damaged by a lateral blast, and an estimated 150 million cubic meters of material were deposited directly by lahars (volcanic mudflows) into the river channels.

What We Know and Need to Learn about Magmatic Systems and Volcanoes

Existing and foreseeable advances in technology allow us to consider a variety of questions critical to advancing our understanding of volcanic systems. Key observations already allow limited volcanic eruption forecasting. For example, under sim-

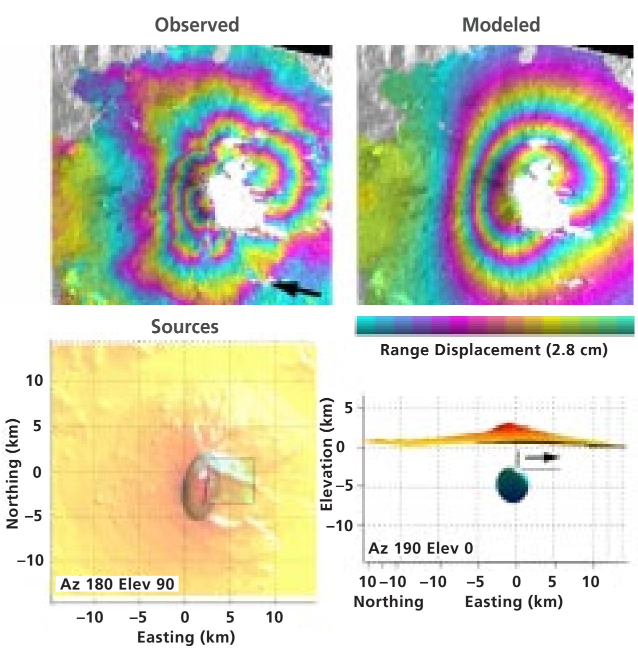


Deformation measured by InSAR at Isabela and Fernandina, islands in the Galápagos archipelago. Also shown is the maximum uplift at each volcano, assuming that displacements are vertical. Differences in the displacement patterns from volcano to volcano illustrate the complex range of deformation mechanisms that can occur.

plifying assumptions of an elastic crust and a limited range of possible magma chamber shapes, available measurements of surface deformation are routinely used to quantify the location and geometry of active magmatic bodies. Recent geodetic observations are also beginning to document a wide variety of complex sources of deformation, including flank instabilities, rift systems, and crater floor dynamics. Recent studies have also demonstrated the ability to measure thermal anomalies associated with volcanic plumes and degassing of SO_2 and CO_2. Many challenges remain, however. We must assess the geometry of the volcanic plumbing system, the physical properties of the magma (composition, volatile content), magma ascent rates, and the location and mechanisms of volatile exsolution. A key question is how we determine a volcano's level of activity, whether by surface deformation, variations in gravity, heat flux, mass transports, seismicity, or gas emissions. At any given time, only one of these manifestations of activity may be present. The extent to which we can currently predict eruptions is largely limited by a lack of observations.

Next Steps

To make significant progress addressing these volcanological challenges, we need a globally comprehensive compilation of observations of all major land volcanoes. This inventory will rely principally on geodetic and spectroscopic observations. From the geodetic standpoint, full vector deformation maps are required to reduce ambiguities in inferences of magma chamber geometry. Given the sporadic nature of volcanic activity, a global archive updated on weekly time intervals is required. Such time intervals would also permit us to gain sensitivity to low-level but more nearly continuous processes. In the event of an eruption, shorter time intervals are desired, with updating several times per day. However, in these cases, only a spotlight view of a targeted area of the globe is needed. A similar rationale holds for the timing of spectroscopic measurements. Such measurements provide sensitivity to heat flux and gas emissions (e.g., SO_2 and CO_2). Given the proper temporal resolution, temperature changes on the order of 0.5 K and accurate measurements of gas emissions, along with surface deformation maps, may allow forecasting of eruptions.



Satellite radar interferometry observations and models of surface deformation of Italy's Mt. Etna volcano prior to eruption shows inflation of the central magma chamber that induced movement of its unstable eastern flank. Bottom row shows a physical model of the magma chamber and fault dislocation solution: left, map view looking through the topography; right, side view, with the sense of flank motion indicated by the arrow.